



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Theory of mind and executive functioning following stroke

Citation for published version:

Hamilton, J, Radlak, B, Morris, P & Phillips, LH 2017, 'Theory of mind and executive functioning following stroke', *Archives of Clinical Neuropsychology*, vol. 32, no. 5, pp. 507-518.
<https://doi.org/10.1093/arclin/acx035>

Digital Object Identifier (DOI):

[10.1093/arclin/acx035](https://doi.org/10.1093/arclin/acx035)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Archives of Clinical Neuropsychology

Publisher Rights Statement:

This is a pre-copyedited, author-produced PDF of an article accepted for publication in Archives of Clinical Neuropsychology following peer review. The version of record Jackie Hamilton, Bogna Radlak, Paul G. Morris, Louise H. Phillips; Theory of Mind and Executive Functioning Following Stroke. Arch Clin Neuropsychol 2017 1-12. doi: 10.1093/arclin/acx035 is available online at:
<https://academic.oup.com/acn/article/doi/10.1093/arclin/acx035/3769480/Theory-of-Mind-and-Executive-Functioning-Following?guestAccessKey=20c99055-48f0-48a3-9cc9-75017731c758>

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Theory of mind and executive functioning following stroke.

Jackie Hamilton^{1*}, Bogna Radlak², Paul G. Morris³ & Louise H. Phillips⁴.

¹ Department of Clinical Neuropsychology, Aberdeen Royal Infirmary, Ashgrove House,
AB25 2ZN, UK, email: jackie.hamilton@nhs.net

² Royal Cornhill Hospital, Aberdeen, UK email: bogumila.radlak@nhs.net

³ Clinical and Health Psychology, University of Edinburgh, Teviot Place Quad, EH8
9AG, UK, email: p.g.morris@ed.ac.uk

⁴ School of Psychology, University of Aberdeen, King's College, AB24 3UB, UK, email:
louise.phillips@abdn.ac.uk

Corresponding author: Dr Jackie Hamilton, Department of Clinical Neuropsychology,
Rm2.19 Ashgrove House, Aberdeen Royal Infirmary, Aberdeen, AB25 2ZN, United
Kingdom. Email: jackie.hamilton@nhs.net.

Please cite as: Hamilton, J., Radlak, B., Morris, P. G., & Phillips, L. H. (2017). Theory of
Mind and Executive Functioning Following Stroke. *Archives of Clinical
Neuropsychology*, 1-12.

Link to publisher version: <https://doi.org/10.1093/arclin/acx035>

Post embargo free-access link:

<https://academic.oup.com/acn/article/doi/10.1093/arclin/acx035/3769480/Theory-of-Mind-and-Executive-Functioning-Following?guestAccessKey=20c99055-48f0-48a3-9cc9-75017731c758>

Abstract

Objective: Cognitive deficits following stroke are well documented, but less is known about problems with social skills such as understanding others' thoughts and feelings. This study investigated the effect of stroke on a visual-affective measure of social understanding: the Reading the Mind in the Eyes test (RMET). The aims were to investigate whether right hemisphere stroke was particularly detrimental to this aspect of Theory of Mind (ToM), and investigate the relationship between ToM ability and executive function following stroke.

Methods: Performance of stroke patients (right hemisphere stroke, $n = 15$; left hemisphere stroke, $n = 15$) was compared to that of controls ($n = 40$) matched for age, years of education and IQ on tasks measuring ToM and executive functioning.

Results: Right hemisphere stroke was associated with impaired ToM ability, but left hemisphere stroke was not. There was no effect of stroke on a matched non-ToM control task. High correlations were found between performance on the RMET and some measures of executive functioning in participants with right hemisphere stroke only. Further analyses suggested that deficits in executive functioning could not statistically explain all of the difficulties shown by stroke participants on the RMET.

Conclusions: A reduction in the ability to attribute mental states to others following right hemisphere stroke may adversely affect psychosocial functioning, disrupt interpersonal relationships, and lead to reduced quality of life. The clinical importance of these findings, implications for clinical practice and future research are discussed.

Key words: stroke, theory of mind, executive functioning, social cognition.

Theory of mind and executive functioning following stroke.

Stroke is an increasingly common neurovascular condition and the third largest cause of death in the UK (Wolfe, 1996), accounting for over 60,000 deaths each year (Allender, Peto, Scarborough, Boxer, & Rayner, 2006). Given that the population as a whole is aging, the number of new cases of stroke, recently estimated at 13,000 in Scotland each year (Scottish Stroke Care Audit, 2011), is likely to increase, putting more financial pressure on health services. Recovery from stroke often entails long-term and intense rehabilitation that focuses primarily on reducing physical limitations. However, even when physical recovery is achieved, enduring psychological and social difficulties can persist (Lai, Studenski, Duncan, & Perera, 2002), affecting social competence of stroke survivors. Physical and cognitive consequences of stroke are well recognised due to past research being mainly focused on these aspects of stroke recovery. However, since successful stroke recovery and rehabilitation is dependent on numerous factors, exploring the factors that affect psychological and social competence of stroke survivors is equally important in improving post-stroke outcomes.

Theory of mind after stroke

One such factor that may influence the psychological and social competence of stroke survivors is impairment in Theory of Mind (ToM). ToM is the ability necessary for comprehending mental states (such as thoughts, feelings, intentions etc.) of other people, and is viewed as essential for successful social communication (Baron-Cohen, 1995; Weed, McGregor, Nielson, Roepstorff, & Frith, 2010), as it forms the basis for predicting the actions of others. More specifically, ToM is regarded as having cognitive and affective components. Cognitive ToM is an ability to distinguish between the knowledge of self and other, and to understand the thoughts, beliefs and intentions of another person,

whereas affective ToM is concerned with understanding others' feelings (i.e. knowledge about emotions) (Shur, Shamay-Tsoory, & Levkovitz, 2008).

Research on ToM in relation to stroke to date has concentrated mainly on focal unilateral brain lesion, investigating whether lateralisation of brain injury influences the magnitude of ToM impairments. Studies that have investigated both right hemisphere lesions (RHL) and left hemisphere lesions (LHL) in stroke participants have produced conflicting results about the lateralisation of ToM function (Griffin et al., 2006; Happé, Brownell, & Winner, 1999; Siegal, Carrington, & Radel, 1996; Surian & Siegal, 2001; Tompkins, Scharp, Fassbinder, Meigh, & Armstrong, 2008; Winner, Brownell, Happé, Blum, & Pincus, 1998; Yeh & Tsai, 2014). Typical ToM tasks used in stroke research require participants to attribute and infer mental states of characters, who often hold false beliefs, from short stories and single-framed cartoons. As such, these tasks tend to measure mainly cognitive ToM. ToM stories, the most commonly used task to assess ToM ability in stroke, induce conflicting mental representations that need to be resolved to correctly interpret thoughts and behaviours of the story characters. Some previous studies have reported stroke participants with RHL to be more impaired than stroke participants with LHL and/or healthy controls on ToM stories (Happé et al., 1999; Siegal et al., 1996; Winner et al., 1998). Also, studies looking at second-order mental state attributions, in which participants need to infer what one character believes about the thoughts and intentions of another character, have suggested a presence of a deficit in stroke survivors with RHL (Griffin et al., 2006; Winner et al., 1998).

These findings suggest that the right hemisphere is important in the cognitive processes that underlie ToM. However, considering the level of task complexity in ToM stories, it might be that a more general impairment in abstract-reasoning or pragmatic inference-making accounts for the ToM impairment (Weed, 2008). In fact, pragmatic

language difficulties after right hemisphere stroke have been widely recognised (see Martin & McDonald, 2003 for a review) and may influence performance on ToM stories that require deriving meaning from social context and discourse interpretation. According to Tompkins et al. (2008) the ToM stories used by Happé et al. included a larger number of perspective shifts, story characters, and times characters were mentioned, compared to supposedly matched control stimuli. After re-writing the control stimuli in order to balance out these potential confounds, Tompkins et al. found no differences in ToM abilities between stroke individuals with RHL and controls. Also, Tompkins et al.'s findings pinpoint a central theoretical issue in measuring ToM abilities, namely the employment of adequate control tasks. Such control tasks allow us to distinguish whether stroke effects reflect a specific deficit in ToM abilities or more general changes in understanding complex linguistic prose or perceiving visual information.

Theory of mind and executive functioning after stroke

Other cognitive processes that are likely to support ToM ability may include aspects of executive functioning (see Perner & Lang, 2000; Aboulafia-Brakha, Christe, Martory, & Annoni, 2011 for a review), such as attentional flexibility, inhibition of prepotent information, and the ability to update information in working memory. Functional interdependence of ToM and executive functioning has been reported (Aboulafia-Brakha et al., 2011; Bora et al., 2005; Channon & Crawford, 2002; Perner & Lang, 2000), and there may be overlap in the complex brain networks involved in both the social cognitive processes involved in ToM and the cognitive regulation processes key to executive function. Individual case studies indicate that a network of brain regions appears to be involved in ToM. In particular, damage to some specific regions of prefrontal cortex (Shamay-Tsoory, Tomer, Berger, & Aharon-Peretz, 2003; Stuss,

Gallup & Alexander, 2001), and regions of the temporal lobes such as the superior temporal sulcus (Apperley, Samson, Chiavarino, & Humphreys, 2004) can disrupt ToM performance.

Given the putative role of prefrontal-cortical-subcortical networks in both ToM and aspects of executive function, a number of studies have investigated the disruption to both processes in patients with lesions localized to prefrontal cortex. Results consistently indicate a dissociation between deficits in ToM and deficits in cognitive control functions which may be associated with specific lesions localised within different areas of prefrontal cortex (Bird, Castelli, Malik, Frith, & Husain, 2004; Fine, Lumsden, & Blair 2001; Rowe, Bullock, Polkey, & Morris, 2001; Bach, Happe, Fleminger, & Powell, 2000; Happé, Malhi, & Checkley, 2001). However, in patients with more widespread aetiology of brain damage likely to disrupt prefrontal connectivity more generally, ToM deficits correlate strongly with aspects of executive dysfunction (Henry, Phillips, Crawford, Ietswaart, & Summers, 2006; Aboulafia-Brakha et al., 2011). It remains unclear whether ToM ability after stroke is related to executive control functions, and no study to date that we are aware of has explored the association between these two constructs in a group study. Given the widespread network of brain connections that might be damaged by stroke, it is plausible that ToM and aspects of executive dysfunction might be related.

The Reading the Mind in the Eyes test (RMET)

Whether problems in interpreting others' thoughts and feelings reflect a very specific and modular deficit, or instead are related to more widespread failures of cognitive function, including executive dysfunction, continues to be a topic of debate. In the context of post-stroke deficits, ToM tasks that are less dependent on language processes and complex cognition than the Stories tasks should be employed to tap ToM

impairments following stroke more directly. The Reading the Mind in the Eyes Test (RMET, Baron-Cohen, Wheelwright, Raste, & Plumb, 2001) has the benefit of relying less on complex language processing than the ToM Stories task, thus enabling the inclusion of individuals with expressive aphasia. The RMET requires participants to look at pictures of the eye region of the face and decide what thought or emotion is being shown. Because the trials in the task require understanding and making decisions about both thoughts (e.g. reflective) and emotions (e.g. worried), it likely taps into both cognitive and affective aspects of ToM (Shur et al., 2008). Visual stimuli may also tap more naturalistic ToM used in everyday situations that often depend on accurate decoding of nonverbal behaviour. The RMET is shorter and less cognitively demanding than the Stories tasks (Bull, Phillips, & Conway, 2008), thus less susceptible to contamination from fatigue, memory impairment or executive dysfunction.

The validity of the RMET as a measure of ToM is supported by evidence that it is sensitive to autism, and scores on the RMET task correlate with performance on classic verbal ToM tasks such as the Strange Stories (Baron-Cohen et al., 2001). Also, performance of the RMET activates similar brain networks to those seen in other ToM tasks, i.e. the superior temporal sulcus and inferior frontal gyrus (Adams et al., 2009). Factor analysis has confirmed that the items on the RMET all load on a single factor (Vellante et al., 2013). Although the RMET has been used in many previous studies (e.g. Vellante et al., 2013, in a selective review, cite over forty published studies using the task), the current study is the first study to use the task in a stroke sample. A matched control task containing no ToM component is also used in the current study to look at the specificity of ToM deficit after stroke.

Objectives

In this study we aim to investigate:

- (1) The differential effects of right hemisphere versus left hemisphere stroke on a measure of visual ToM (RMET) and whether these effects are specific to ToM impairment.
- (2) Whether stroke participants' performance on the measure of ToM (RMET) is related to their scores on measures of executive functioning, particularly cognitive flexibility and set shifting (verbal fluency) and response flexibility and inhibition (Brixton test).

Methods

Participants

Thirty stroke participants and 40 demographically matched healthy controls took part in this study, after giving their informed consent. Ethical approval was given by the NHS Grampian Research Ethics Committee. Handedness was determined by self-report and all participants were right-handed with the exception of one male in the healthy control group. The National Adult Reading test (NART-R) (Nelson & Willison, 1991) was used in this study as a measure of pre-morbid intelligence (IQ) in the stroke participants, and to ensure that all stroke participants and control participants fell at least within the average range for IQ.

For the stroke sample, participants were recruited from the post acute stroke rehabilitation ward at Woodend Hospital, Aberdeen. Seven males and eight females with LHL, as well as seven males and eight females with RHL were recruited. Clinical features (e.g. type of stroke using the Oxford classification system, (Bamford and Sandercock, 1991), location of lesion and length of time since stroke) were obtained from the medical records. Lesion evidence was based on medical interpretation of clinical

radiological MRI or CT report. The stroke survivors were included if they had experienced a first ever ischaemic stroke ($n = 28$) or haemorrhagic infarct ($n=2$) localised in one hemisphere within the past six months. All stroke participants received speech and language intervention, occupational therapy and physiotherapy, as required as part of their ongoing rehabilitation. No participants received formal cognitive rehabilitation due to the limited clinical neuropsychology provision in this setting. A healthy control group; 18 males and 22 females, were recruited via a local community group. Stroke and control participants were excluded from the study if they met any of the following criteria: 1) English was not their first language, 2) they were incapable of informed consent, 3) they had a previous or current medical history which is known to affect social processing or cognitive functioning (e.g. autism, dementia, significant brain/head injury, substance/alcohol abuse, anxiety disorder), 4) previous or current history of psychosis, 5) currently aphasic or suffering from moderate/ severe expressive or receptive aphasia, 6) they had uncorrected visual or hearing impairments.

Procedure

The measures were administered in accordance with the relevant manual instructions, although the RMET was modified slightly by asking the participant to read out loud or point to each of the four words before making their choice. This was in order to compensate for the possible presence of visual neglect, which commonly occurs following stroke. Similarly, some individuals in the stroke group suffered from mild expressive aphasia ($n = 7$), and it was therefore not appropriate to administer some of the other tasks, such as the NART and Verbal Fluency task. The task order was counterbalanced to minimise order effects, although the NART was always administered

after the Verbal Fluency task. This was to prevent the possibility of participants using words from the NART to enhance verbal fluency performance.

Measures

The theory of mind (ToM) Reading the Mind in the Eyes test (RMET).

The 'Reading the Mind in the Eyes' test (RMET) (Baron-Cohen, et al., 2001), consists of black and white photographs of the eye region of the face. Participants are asked to choose a word, from a possible four, which they believe best describes what the person in the picture is thinking or feeling (e.g. fantasising, worried, reflective, preoccupied etc.). Twenty-six pictures (1 practice, and 25 test items) from the test were used in this study, excluding ten items from the original test which were found during pilot work to have ceiling or floor effects (Bull et al., 2008, Slessor, Phillips, & Bull, 2007). It is argued that successful completion of this task is dependent on an adequate conception of another's mental states, and an ability to attribute mental states and emotions of others (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997). This test was chosen because it has less cognitive load and a lower verbal component than other commonly used ToM tasks such as the ToM stories test (Happé et al., 1999) or the faux pas test (Stone, Baron-Cohen, & Knight, 1998). The dependent measure was the total number of correct responses.

The Eyes control task

The Eyes control task was designed to investigate the specificity of any group differences in ToM. Using the same photographs used in the RMET, Baron-Cohen and colleagues (2001) developed a separate control task for the RMET in which subjects are asked to judge the sex of the person: however performance on this approached ceiling.

Developing this further, Slessor et al. (2007) modified the Eyes control task, so that participants are required to make age and sex judgments about the person presented in the stimuli, from a choice of possible four sex/age range answers (e.g. Male 40-50, Female 40-50, Female 50-60, Male 50-60). The four possible answers differed for each item, and were carefully piloted to establish that the control task was of roughly equivalent difficulty to the RMET task (Slessor et al., 2007). The dependent measure was the total number of correct responses.

Verbal fluency task: the Letter Fluency trials & Category Fluency trial.

Reduced verbal fluency is considered to reflect poor cognitive control in terms of impaired mental flexibility and difficulty shifting cognitive set (Mitrushina, Boon, & D'Elia, 1999; Baldo & Shimamura, 1998). The most common Verbal Fluency task consists of four word-naming trials; three letters, and one category. The Letter Fluency stimuli used in this study were the letters 'F', 'A', and 'S'. For each letter, participants were required to say as many words as they could in one minute beginning with that letter, excluding proper nouns and the same word with a different suffix. The Category Fluency cue was 'animals': participants were asked to generate as many animal names as they could think of in one minute (Gladsjo, Miller, & Heaton, 1999). The dependent measure for each task was the total number of correct responses, minus repetitions and inappropriate responses.

The Brixton test.

The Brixton test (Burgess & Shallice, 1997) is a rule detection and rule following task designed to assess executive function. In addition to assessing the ability to detect and follow a rule, the task also assesses response flexibility to the changing rules. Burgess

and Shallice (1996) found that people with frontal lobe lesions were generally poorer at the Brixton test than either controls or patients with posterior lesions, and tended to make more bizarre or guessing errors. Performance on the Brixton test predicts dysexecutive behaviour in everyday life (Odhuba, van de Broek, & Jones, 2005). In a 56 page stimulus book each page showed the same array of ten circles, with one of the circles being filled in. The position of this filled circle differed from page to page. The participant was shown one page at a time and was asked to guess where the next filled position would be, by trying to identify a 'rule', based on what they have seen on previous pages. The dependent measure was the total number of errors made.

National Adult Reading test (NART).

The National Adult Reading test (NART-2; Nelson & Willison, 1991) was specifically designed to provide a means of estimating the pre-morbid IQ of adult patients. The NART comprises a list of 50 words printed in order of increasing difficulty, and they are all 'irregular' or 'atypical' with respect to the common rules of pronunciation. Therefore, applying the common grapheme-phoneme and stress rules of the English language would result in incorrect pronunciation, and it has been argued the words can only be read and pronounced correctly if the participant is familiar with their written form (Nelson & Willison, 1991). Participants read the word list aloud, and the number of errors made was recorded. The dependent measure was predicted IQ.

Beck Depression inventory (BDI-II).

The revised Beck Depression inventory (BDI-II; Beck, Steer, & Brown, 1996) is a 21-item self-report depression screening measure and has become one of the most widely accepted measures for assessing the severity of depression in diagnosed individuals, and

for detecting possible depression in normal populations (Beck et al., 1996). Depression is known to be a common consequence of stroke, and can affect cognitive functioning. There is also evidence to suggest that individuals who are depressed are biased in their judgments of emotions in others (Leppanen, Milders, Bell, Terriere, & Hietanen, 2004). It was therefore used in this study as an attempt to control for the possibility of depression affecting performance on the RMET. The score is the sum of all the selected statements with the maximum score being 63. The higher the overall score the more depressed the individual is likely to be. Three participants in the study met criteria for mild-moderate depression based on their BDI scores: one control, one person with left hemisphere stroke and one with right hemisphere stroke. All analyses were re-run excluding these participants and this did not alter the pattern of results reported below. Also note that BDI scores did not correlate with any of the measures in this study (RMET or the executive function measures).

Results

Demographic data

Statistical analyses showed no significant differences between healthy controls and participants with RHL or LHL stroke in terms of male-female ratio, $\chi^2(2) = .019$, $p = .99$, age, $F(2, 67) = 0.071$, $p = .93$, years of education, $F(2, 67) = 0.83$, $p = .44$, NART predicted IQ, $F(2, 67) = 2.06$, $p = .14$, or depression scores as measured by the BDI, $F(2, 67) = 0.22$, $p = .80$. Means (M) and standard deviations (SD) for age, years of education, NART predicted IQ and the BDI are listed in Table 1. Note that seven out of 15 left hemisphere stroke participants could not complete the NART due to mild expressive aphasia.

Time since stroke was computed by totalling the number of days that had passed between date of stroke and date of testing. The mean number of days post stroke for both the RHL and LHL groups is also included in Table 1. No statistically significant difference was found between the two stroke groups in terms of mean time post stroke, $F(1, 28) = 0.30, p = .59$, therefore, this variable was not included in further analyses.

The RMET & the Eyes Control test

Table 2 summarises performance of stroke and control groups on ToM and executive function measures. Raw scores for all tasks were used in the analyses. A one-way ANOVA comparing the three groups on the RMET revealed that the difference between groups was significant, $F(2, 67) = 18.5, p < .001, \eta_p^2 = .36$. Further examination using Scheffe's post-hoc analysis ($p < .05$) revealed that the stroke group with RHL had significantly fewer correct ToM judgments than either the stroke group with LHL or healthy controls. There was no difference between the LHL stroke group and healthy controls. No significant group effect was found on the Eyes Control test, $F(2, 67) = 2.63, p = .079$.

Executive function measures: the Brixton test and the Verbal Fluency task

There was a significant difference between groups on the Brixton test, $F(2, 67) = 12.4, p < .001, \eta_p^2 = .27$. Scheffe's post hoc comparisons showed that both stroke groups with RHL and LHL were significantly impaired on the Brixton test compared to the control group, but that the stroke groups did not differ from each other. With regards to the Verbal Fluency task, for the Category Fluency trial, there was a significant effect of group, $F(2, 60) = 16.7, p < .001, \eta_p^2 = .36$. Again, both stroke groups' scores were significantly lower than the controls, but did not differ from each other. For the Letter

Fluency trials, there was a significant effect of group, $F(2, 60) = 8.21, p = .001 \eta_p^2 = .22$, with the stroke group with RHL performing significantly worse than the healthy control group. There was no significant difference in performance between the stroke group with LHL and either of the other groups, however this comparison lacks power because seven out of 15 participants with LHD could not complete the fluency tasks due to mild expressive aphasia.

The relationship between performance on the RMET and scores on the executive function measures for the stroke groups and healthy controls

Table 3 shows correlations between the RMET performance and scores on the three executive functioning tasks separately for each group. In the stroke group with RHL, the performance on the RMET was significantly correlated with the Brixton test performance, as well as the Category Fluency performance. Also, significant correlations were found between the two different types of fluency. In the stroke group with LHL none of the correlations were significant. In the healthy control group, the performance on the RMET was significantly correlated with Category Fluency. Other significant correlations were found between some of the different executive function measures (Letter Fluency with both Brixton task performance and Category Fluency).

Analysis of RMET using the executive functioning measures as covariates

To investigate whether there were differences in stroke and control participants' RMET performance after controlling for measures of executive functioning, ANCOVA was carried out. In the analysis, the total number of correct responses on the RMET was entered as a dependent variable, whereas the total number of errors on the Brixton test, and total number of correct responses on the Category Fluency and Letter Fluency trials

were entered as covariates. Category Fluency score significantly predicted performance on the RMET, $F(1, 57) = 5.37, p = .024, \eta_p^2 = .086$ but neither of the remaining covariates significantly predicted performance on the RMET, $F(1, 57) = 2.37, p = .13$ for the Brixton test, and $F(1, 57) < 1, p = .92$ for the Letter Fluency trials. Once the three executive function measures were co-varied, the group difference in performance on the RMET remained highly significant, $F(2, 57) = 6.58, p = .003, \eta_p^2 = .19$.

Discussion

This study explored the effects of stroke on a measure of social understanding: the RMET. The aims were to differentiate the effects of right hemisphere versus left hemisphere stroke on this visual ToM task performance and to investigate whether ToM ability after stroke is related to aspects of executive dysfunction.

Theory of Mind (ToM) impairments after stroke

The results showed that stroke participants with RHL were significantly more impaired on the visual RMET than those with LHL, who performed similarly to healthy controls. This finding is in line with the previous literature investigating ToM impairments after stroke that used mainly linguistically complex ToM stories (Griffin et al., 2006; Happé et al., 1999, Siegal et al., 1996, & Winner et al., 1998). It has been questioned whether these impairments tap ToM directly (Weed, 2008). The RMET has the benefit of being less dependent on social language skills that are so frequently impaired after stroke. Current results suggest that the right hemisphere has a crucial role in supporting ToM ability. We tried to control for cognitive and perceptual factors involved in the RMET through our use of a matched control task which involved the same photographs and similarly difficult choices between four options. No significant

differences were found between the groups in performance on the Eyes Control test containing no ToM component, which makes it unlikely that the observed ToM deficit of stroke participants with RHL is simply an artefact of impairment in visuo-spatial abilities necessary for mental state attribution. It can therefore be concluded that the impaired performance on the RMET of the stroke participants with RHL in this study reflects a specific rather than more general cognitive or perceptual deficit. However, it must be noted that the level of semantic analysis involved in discriminating between mental state terms is greater than that involved in making age-gender judgments, and it would be useful in future research to develop a more linguistically complex non-ToM equivalent for future research.

Executive function impairments after stroke

Further analysis showed that stroke participants with both RHL and LHL performed significantly worse on the Brixton test of executive function, as compared to healthy controls. However, the two stroke groups did not differ significantly from each other. This is consistent with previous findings showing executive dysfunction as a common problem following brain injury, irrespective of the side of lesion (Stuss & Levine, 2002). The finding that there were no significant differences between the stroke groups suggests the Brixton test and the RMET are measuring different constructs. A similar pattern was found on the Category Fluency task. However, for the Letter Fluency trials, only the stroke group with RHL performed significantly worse than healthy control group. This specific finding may be explained by the fact many individuals with language difficulties in the stroke group with LHL did not perform the letter fluency task. Therefore, this finding may not give an accurate reflection of the difficulties an individual with LHL may have with this aspect of executive functioning (i.e. mental flexibility).

Theory of mind and executive function after stroke

This study also explored the relationship between ToM ability and executive functioning in the context of stroke. Current results indicated that performance on the RMET was strongly correlated with the performance on the Brixton test of executive function, although only in the stroke group with RHL. Furthermore, performance on the RMET was also strongly correlated with the performance on the Category Fluency trial in this stroke group, and only moderately correlated in the healthy control group. The correlation between the RMET and the Brixton test of executive function could be argued to reflect shared visual components, rather than necessarily indicating a link between executive dysfunction. However this would not be the case for the correlation with the Category Fluency trial which is dependent on verbal ability. Thus, these findings suggest that performance on the RMET is dependent, in part, on cognitive control processes such as ability to shift mental set. While Category Fluency is traditionally seen as a measure of semantic organisation sensitive to temporal lobe damage, it also involves control processes such as mental set-shifting to aid retrieval (as evidenced by dual task studies, e.g. Rende, Ramsberger & Miyake, 2002). Also meta-analytic evidence suggests that frontal lobe damage has similar effects on both letter and category fluency (Henry & Crawford, 2004), again supporting the involvement of cognitive control processes in the task.

Some suggest (e.g. Hughes & Russell, 1993) that ToM measures tap such control processes as cognitive flexibility and response inhibition. There is evidence for a strong association between ToM and executive functioning (Aboulafia-Brakha et al., 2011; Bora et al., 2005; Channon & Crawford, 2000). However other studies present evidence for a dissociation between the two constructs (Bach et al., 2000; Lough & Hodges, 2002).

Significant correlations were not found between ToM and executive function measures for those with left hemisphere stroke lesions. For the verbal fluency tasks, this lack of correlations likely reflects the small numbers completing the measures, given that many of those with LHL also had expressive aphasia. It is of note that the effect size of the correlations between RMET and fluency is similar in all groups. More interesting is the finding that the LHL group showed no correlation between the RMET and the Brixton test of executive function, which was not dependent on spoken language. The correlation between Brixton performance and RMET scores in the RHL, but not the LHL groups, suggests that right hemisphere damage specifically leads to related problems with both executive control and theory of mind.

When ANCOVA was carried out to further investigate the group effect on ToM while co-varying executive functioning performance, the results showed that the performance on the Category Fluency trial was the only covariate significantly associated with performance on the RMET. However, the group effect on ToM persisted after co-varying for executive functioning. This suggests that the difference in performance on the RMET was not driven by the deficit in executive functioning. Hence, it is reasonable to assume that stroke had a primary impact on the RMET performance in this study. An important limitation to note here is that we only carried out brief assessment of executive function, and it would be useful to carry out a broader battery of cognitive control tasks aimed at assessing updating, switching, and inhibition in future studies using the RMET.

Limitations of the current study and suggestions for future research

A strength of this study in understanding relationships between brain and behaviour is that all of the brain injury participants had the same aetiology, stroke. However, the initial presentation of haemorrhagic stroke is often qualitatively different

from ischaemic stroke. Only two of the participants in the current study had haemorrhagic stroke, and they were not outliers on any of the tasks. However, it would be useful in future research to explore the effects of different types of stroke on this area of functioning and its recovery over time. There are also issues concerning lesion specificity following stroke, which are common to most brain injured population studies. The very nature of stroke means that often individuals may have experienced asymptomatic strokes or prolonged transient ischaemic attacks in addition to the main stroke, which have been shown to result in infarction of brain tissue (Bogousslavsky, Hommel, & Basetti, 1998). It is therefore possible that some individuals in this study had further lesions to other areas of the brain which was not apparent on scans, similar to the findings following traumatic brain injury (TBI). Similarly, the brain imaging had in all cases been undertaken in the early stages following stroke to establish cause of symptomatology and guide clinical management. As Happé et al. (1999) highlight, the final pattern of tissue damage may not be revealed by scans at this early stage owing to secondary physiological processes, which could result in either further damage or recovery of brain tissue being possible. Therefore, lesion information should be viewed with caution.

A related issue concerns the length of time that had passed between the occurrence of stroke and date of testing. It could be argued that the individuals in this study were still in the early stages of recovery (see Table 1). It is well known focal neurological symptoms, as well as perceptual and attentional impairments have been found to recover markedly in the first 6 months post-stroke (Montagne, Nys, van Zandvoort, Kappelle, & de Haan, 2007). However, the rationale for testing stroke participants in the post-acute stage of recovery was primarily because, in clinical rehabilitation settings, this is often the time when emotional or behavioural difficulties become apparent. Whether the difficulties found in this study are longstanding or not

would require further research. However, there is evidence to suggest that for some individuals, these difficulties will remain (Hochstenbach, den Otter, & Mulder, 2003; Rasquin et al., 2004; Happe et al., 1999).

Also, since ToM abilities are generally regarded as essential for successful social functioning (Baron-Cohen, 1995; Weed, McGregor, Nielsen, Roepstorff, & Firth, 2010), it would be interesting to see whether impaired ability to attribute mental states to others affects psychosocial functioning, disrupts interpersonal relationships and leads to reduced quality of life. Yet, up till now, the emphasis of previous studies including this one, has been on focal unilateral brain damage, exploring the role of each hemisphere in ToM abilities. Future studies should explore how such impairments in ToM influence social functioning outcomes of stroke survivors and their quality of life. Another factor to consider is gender. There is evidence for a female advantage on ToM tasks such as the RMET (Vellante et al., 2013), and it would be useful in larger scale stroke studies in future to explore whether the pattern of deficits in ToM and social consequences differ in men and women.

This study was motivated by an interest in improving clinical understanding and awareness of the social and emotional problems which can follow stroke. Like many clinically-based studies of ToM we used the very basic classification of left versus right hemisphere lesion to investigate deficits, and this has shown a clear association of right hemisphere damage with ToM impairment. Showing this association between side of lesion and ToM impairment may prove useful for daily clinical practice and assessment. However, to provide more detailed theoretical understanding of the brain-behaviour associations between site of lesion and ToM in future, it will be necessary to conduct studies which used more sophisticated structural imaging analysis to pinpoint more clearly the links between specific brain networks and ToM performance. This is

important to inform theoretical understanding of ToM. We did not have access to full structural scans for all stroke participants in the current study, but an important goal for future research would be to use composite imaging techniques to provide a clearer association between tasks such as the RMET and locations of brain damage.

A limitation of this study is that it focused only on the RMET to assess ToM. The Eyes test involves a basic emotion recognition element (Baron-Cohen et al., 2001), and therefore it is possible that it does not measure the ToM construct directly, rather it taps emotion recognition ability. While some trials in the RMET ask about mental states that are not basic emotions (e.g. preoccupied, reflective) others have a stronger emotional component. It would be useful to more clearly separate out the role of emotion perception and understanding of non-affective mental states in those with right hemisphere strokes. There is evidence that right hemisphere brain damage impairs recognition of basic expressions of emotion more often than left hemisphere damage (e.g. Kucharska-Pietura et al., 2003). Future studies should therefore use a basic emotion recognition measure as well, to control for this. Another issue is that the response options in the RMET may be biased, limiting the construct validity of the task as a measure of ToM (Johnson, Miles & McKinlay, 2008). A further limitation of the RMET is that it measures only a restricted range of different information conveyed through social interactions in real-life (e.g. gestures, verbal cues or context are not assessed by this task). Thus, it would be desirable to use it in conjunction with other ToM measures (e.g. video clips) that tap other socially relevant information. The long-term aim should be to validate in stroke samples measures that are more naturalistic than the RMET (e.g. the Awareness of Social Inference Test; McDonald, Flanagan & Rollins, 2002) in order to delineate exactly which aspects of ToM are affected after stroke. This is important as increased understanding of the nature

of any impairment in social functioning is central to improved clinical management and rehabilitation.

Clinical implications

Recovery from stroke often entails long-term and intense rehabilitation that focuses primarily on reducing physical limitations. However, even when physical recovery is achieved, enduring psychological and social difficulties can persist (Lai, Studenski, Duncan, & Perera, 2002). At present, it is recommended that individuals who have been admitted to stroke rehabilitation wards are screened for mood disorders, which commonly occur following stroke (SIGN, 2010), and cognitive screening is increasingly becoming common practice. There appears to be less awareness however of the potential challenges individuals may have in dealing with social situations as a result of social cognition difficulties secondary to stroke.

The results of this study suggest that individuals who have experienced right-hemisphere stroke may be particularly susceptible to deficits in an aspect of social cognition commonly referred to as theory of mind (ToM). Showing this association between side of lesion and ToM impairment may prove useful for daily clinical practice and assessment by highlighting those individuals who may be most at risk of experiencing these types of social communication problems following stroke. Impaired ability to attribute mental states to others can interfere with how individuals use information conveyed through social interaction and can, in turn, impact on interpersonal relationships and social roles, potentially leading to reduced social participation and quality of life. Such difficulties are also known to affect rehabilitation progress (Hartman-Maeir, Soroker, Ring, & Katz, 2002). As such, these results have important implications for the process of rehabilitation and relevance for relatives, carers and other professionals.

An initial step towards improving this aspect of social functioning would be to identify the nature and extent of difficulties presented. Consequently, there may be merit in screening for these types of social functioning deficits as part of routine assessment and when assessing rehabilitation progress and overall outcome following stroke (Carota, Staub, & Bogousslavsky, 2002). The RMET is a quick and simple measure to administer and score, and is relatively stress free for patients to complete. Using the RMET, or similar, as a screening measure for these types of difficulties, may detect the often subtle deficits in the ability to attribute mental states. Information gained through the use of such measures could be used to identify patients who may benefit from compensatory strategies, such as encouraging significant others to convey emotions, meanings or intentions more explicitly or in written form.

Clinical experience has shown that providing a cognitive or psychological explanation for observed behaviours can be extremely helpful for patients, families and other professionals, even if it only serves to increase understanding of the individual and their experience.

Conclusions

The study aimed to explore the differential effects of right hemisphere versus left hemisphere stroke on a measure of ToM (the RMET), and investigate the relationship between ToM ability and executive function following stroke. The results revealed that the stroke participants with RHL were significantly impaired on the RMET, as compared to healthy controls and the stroke participants with LHL. The fact that the stroke participants showed no impairments on a non-ToM control measure suggests that the right hemisphere stroke- related impairment on the ToM measure is specific to mental state reasoning per se.

The stroke participants with both RHL and LHL were impaired on most executive function measures. However, only the executive performance of stroke participants with RHL was highly correlated with their impaired performance on the ToM measure. The current findings extend our knowledge of the ToM impairments that can result from stroke by exploring more naturalistic visual ToM that depends on decoding nonverbal behaviour and by investigating the contributions of executive functioning in ToM judgements. An impaired ability to attribute mental states to others may interfere with how individuals use information conveyed through social interaction and can, in turn, be detrimental for psychological and social functioning. Consequently, screening for these types of ToM impairments as part of routine clinical assessment appears important. Increased identification of any impairment in social functioning would enable individuals to be more appropriately supported and is central to improved clinical management and rehabilitation.

Funding:

This research was not supported by external funding.

Acknowledgements:

The authors wish to thank Dr Maggie Whyte, Consultant Clinical Neuropsychologist and Dr Fiona Summers, Consultant Clinical Neuropsychologist for their advice and support before and during the project; Dr Alastair Cozens, Consultant in Rehabilitation Medicine for his advice in planning stages of the project, as well as Staff on the Stroke Rehabilitation Ward at Woodend Hospital, Aberdeen. Most importantly, we would like to thank all the participants who kindly agreed to take part in this study.

References

- Aboulafia-Brakha, T., Christel, B., Martory, M. D., & Annoni, J. M. (2011). Theory of mind tasks and executive functions: A systematic review of group studies in neurology. *Journal of Neuropsychology*, 5, 39–55.
- Adams, R. B. Jr., Rule, N. O., Franklin, R. G. Jr., Wang, E., Stevenson, M. T., Yoshikawa, S., . . . Ambady, N. (2009). Cross-cultural reading the mind in the eyes: An fMRI investigation. *Journal of Cognitive Neuroscience*, 22, 98-108.
- Allender, S., Peto, V., Scarborough, P., Boxer, A., & Rayner, M. (2006). *Coronary Heart Disease Statistics*. BHF: London
- Apperly, I. A., Samson, D., Chiavarino, C., & Humphreys, G.W. (2004). Frontal and temporo-parietal lobe contributions to theory of mind: Neuropsychological evidence from a false-belief task with reduced language and executive demands. *Journal of Cognitive Neuroscience*, 16, 1773-1784.
- Bach, L. J., Happe, F., Fleming, S., & Powell, J. (2000). Theory of mind: Independence of executive function and the role of the frontal cortex in acquired brain injury. *Cognitive Neuropsychiatry*, 5, 175-192.
- Baldo, J. V., & Shimamura, A. P. (1998). Letter and category fluency in patients with frontal lobe lesions. *Neuropsychology*, 12, 259-267.

Bamford, J. & Sandercock, P (1991). Classification and natural history of clinically identifiable subtypes of cerebral infarction. *Lancet*, 337 (8756), 1521-1526.

Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and theory of mind*. Cambridge, MA: MIT Press.

Baron-Cohen, S., Jolliffe, T., Mortimore, C., & Robertson, M. (1997). Another advanced test of theory of mind: Evidence from very high-functioning adults with autism or Asperger Syndrome. *Journal of Child Psychology and Psychiatry*, 38, 813-822.

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The 'Reading the Mind in the Eyes' test revised version: A study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry*, 42, 241-251.

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Beck Depression Inventory – II, Manual*. San Antonio, TX: Psychological Corporation.

Bird, C. M., Castelli, F., Malik, O., Frith, U., & Husain, M. (2004). The impact of extensive medial frontal lobe damage on 'Theory of Mind' and cognition. *Brain*, 129, 914-918.

Bogousslavsky, J., Hommel, M. & Basetti, C. (1998). Stroke. In M. Swash (Ed.), *Outcomes in neurological and neurosurgical disorders*. Cambridge: Cambridge University Press.

Bora, E., Vahip, S., Gonoul, A. S., Akdeniz, F., Alkan, M., Ogut, M., & Eryavuz, A. (2005). Evidence for theory of mind deficits in euthymic patients with bipolar disorder. *Acta Psychiatrica Scandinavica*, 112, 110-116.

Bull, R., Phillips, L. H., & Conway, C. A. (2008). The role of control functions in mentalizing: dual task studies of theory of mind and executive function. *Cognition*, 107, 663 – 672.

Burgess, P.W., & Shallice, T. (1996). Bizarre responses, rule detection, and frontal lobe lesions. *Cortex*, 32, 241-259.

Burgess, P. W., & Shallice, T. (1997). *The Hayling and Brixton tests: Two tests of dysexecutive syndrome, test manual*. Bury, St Edmunds: Thames Valley Test Company.

Carota, A., Staub, F. & Bogousslavsky, J. (2002). Emotions, behaviours and mood changes in stroke. *Current Opinion in Neurology*, 15, 57-69.

Channon, S., & Crawford, S. (2000). The effects of anterior lesions on performance on a story comprehension test: left anterior impairment on a theory of mind-type task. *Neuropsychologia*, 38, 1006-1017.

Fine, C., Lumsden, J., & Blair, R. J. R. (2001). Dissociation between theory of mind and executive functions in a patient with early amygdale damage. *Brain*, 124, 287-298.

Gladsjo, J. A., Miller, S.W., & Heaton, R. K. (1999). *Norms for letter and category fluency: Demographic corrections for age, education, and ethnicity, test manual*. Lutz, USA: Psychological Assessment Resources, Inc.

Griffin, R., Friedman, O., Ween, J., Winner, E., Happé, F., & Brownell, H. (2006). Theory of mind and the right cerebral hemisphere: Refining the scope of impairment. *Laterality: Asymmetries of Body, Brain and Cognition*, 11, 195-225.

Happé, F., Brownell, H., & Winner, E. (1999). Acquired „theory of mind“ impairments following stroke. *Cognition*, 70, 211-240.

Happe, F., Malhi, G. S., & Checkley, S. (2001). Acquired mind-blindness following frontal lobe surgery? A single case study of impaired ‘theory of mind’ in a patient treated with stereotactic anterior capsulotomy. *Neuropsychologia*, 39, 83-90.

Hartman-Maeir, A., Soroker, N., Ring, H., & Katz, N. (2002). Awareness of deficits in stroke rehabilitation. *Journal of Rehabilitation Medicine*, 34, 158-164.

Henry, J. D., & Crawford, J. R. (2004). A meta-analytic review of verbal fluency performance following focal cortical lesions. *Neuropsychology*, 18, 284-295.

Henry, J. D., Phillips, L. H., Crawford, J. R., Ietswaart, M., & Summers, F. (2006). Theory of mind following traumatic brain injury: The role of emotion recognition and executive dysfunction. *Neuropsychologia*, 44, 1623-1628.

Hochstenbach, J. B., den Otter, R., & Mulder, T.W. (2003). Cognitive recovery after stroke: a 2-year follow-up. *Archives of Physical Medicine and Rehabilitation*, 84, 1499-1504.

Hughes, C., & Russell, J. (1993). Autistic children's difficulty with mental disengagement from an object: Its implications for theories of autism. *Developmental Psychology*, 29, 498–510.

Johnston, L., Miles, L., and McKinlay, A. (2008). A critical review of the Eyes Test as a measure of social cognitive impairment, *Australian Journal of Psychology*, 60, 135-141.

Kucharska-Pietura, K., Phillips, M. L., Gernand, W., & David, A. S. (2003). Perception of emotions from faces and voices following unilateral brain damage. *Neuropsychologia*, 41, 1082-1090.

Lai, S. M., Studenski, S., Duncan, P. W., & Perera, S. (2002). Persisting consequences of stroke measured by the stroke impact scale. *Stroke*, 33, 1840-1844.

Leppanen, J. K., Milders, M., Bell, J. S., Terriere, E., & Hietanen, J. K. (2004). Depression biases the recognition of emotionally neutral faces. *Psychiatry Research*, 128, 123-133.

Lough, S., & Hodges, J. R. (2002). Measuring and modifying abnormal social cognition in frontal variant frontotemporal dementia. *Journal of Psychosomatic Research*, 53, 639–646.

Martin, I., & McDonald, S. (2003). Weak coherence, no theory of mind, or executive dysfunction? Solving the puzzle of pragmatic language disorders. *Brain and Language*, 85, 451-466.

McDonald, S., Flanagan, S., & Rollins, J. (2002). The Awareness of Social Inference Test (TASIT). Bury St Edmunds, UK: Thames Valley Test Company.

Mitrushina, M. N., Boon, K. B., & D'Elia, L. F. (1999). *Handbook of Normative Data for Neuropsychological Assessment*. New York: Oxford University Press.

Montagne, B., Nys, G. M. S., van Zandvoort, M. J. N., Kappelle, L. J., de Haan, E. H. F., & Kessels, R. P. C. (2007). The perception of emotional facial expressions in stroke patients with and without depression. *Acta Neuropsychiatrica*, 19, 279-283.

Nelson, P. G., & Willison, J. (1991). *The National Adult Reading Test (NART): test manual (2nd Ed.)*. Windsor, UK: NFER Nelson.

Odhuba, R. A., van de Broek, M. D., & Johns, L. C (2005). Ecological validity of measures of executive functioning. *British Journal of Clinical Psychology*, 44, 269-278.

Perner, J., & Lang, B. (2000). Theory of mind and executive function: Is there a developmental relationship? In S. Baron-Cohen, H. Tager-Flusberg & D. J. Cohen

(Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience*. (2nd ed., pp.150-181). Oxford: Oxford University Press.

Rasquin, S. M. C., Lodder, J., Ponds, R. W. H. M., Winkens, L., Jolles, J. & Verhey, F. R. J. (2004). Cognitive functioning after stroke: A one-year follow-up study. *Dementia and Geriatric Cognitive Disorders*, 18, 138-144.

Rende, B., Ramsberger, G., & Miyake, A. (2002). Commonalities and differences in the working memory components underlying letter and category fluency tasks: a dual-task investigation. *Neuropsychology*, 16, 309-321.

Robinson, R. G. (1998). *The Clinical Neuropsychiatry of Stroke: Cognitive, behavioural and emotional disorders following vascular brain injury*. Cambridge: Cambridge University Press.

Rowe, A. D., Bullock, P. R., Polkey, C. E., & Morris, G. (2001). 'Theory of Mind' impairments and their relationship to executive functioning following frontal lobe excisions. *Brain*, 124, 600-616.

Scottish Stroke Care Audit. (2011). National Report Stroke Services in Scottish Hospitals; Data relating to 2005-2009. Retrieved June 17, 2012 from http://www.strokeaudit.scot.nhs.uk/Downloads/2011_National_Report.html

Scottish Intercollegiate Guidelines Network (SIGN). (2010). Management of Patients with Stroke: Rehabilitation, Prevention, and Management of Complications, and Discharge Planning: A National Clinical Guideline, No. 118. Edinburgh: SIGN Executive.

Shamay-Tsoory, S. G., Tomer, R., Berger, B. D., & Aharon-Peretz, J. (2003). Characterisation of empathy deficits following prefrontal brain damage: The role of the right ventromedial prefrontal cortex. *Journal of Cognitive Neuroscience*, 15, 324-337.

Shur, S., Shamay-Tsoory, S. G., & Levkovitz, Y. (2008). Integration of emotional and cognitive aspects of theory of mind in schizophrenia and its relation to prefrontal neurocognitive performance. *Cognitive Neuropsychiatry*, 13, 472-490.

Siegal, M., Carrington, J., & Radel, M. (1996). Theory of mind and pragmatic understanding following right hemisphere damage. *Brain and Language*, 53, 40-50.

Slessor, G., Phillips, L. H., & Bull, R. (2007). Exploring the specificity of age-related differences in theory of mind tasks. *Psychology and Aging*, 22, 639-643.

Stone, V. E., Baron-Cohen, S., & Knight, R.T. (1998). Frontal lobe contributions to theory of mind. *Journal of Cognitive Neuroscience*, 10, 640-656.

Stuss, D. T., Gallup, G. G., & Alexander, M. P. (2001). The frontal lobes are necessary for theory of mind. *Brain*, 124, 279-286.

Stuss, D. T., & Levine, B. (2002). Adult clinical neuropsychology: Lessons from studies of the frontal lobes. *Annual Review of Psychology*, 53, 401-433.

Surian, L., & Siegal, M. (2001). Sources of performance on theory of mind tasks in right hemisphere-damaged patients. *Brain and Language*, 78, 224-232.

Tompkins, C. A., Scharp, V. L., Fassbinder, W., Meigh, K. M., & Armstrong, E. M. (2008). A different story on “Theory of Mind” deficit in adults with right hemisphere brain damage. *Aphasiology*, 1, 42–61.

Vellante, M., Baron-Cohen, S., Melis, M., Marrone, M., Petretto, D.R., Masala, C. & Preti, A. (2013) The “Reading the Mind in the Eyes” test: Systematic review of psychometric properties and a validation study in Italy, *Cognitive Neuropsychiatry*, 18, 326-354.

Weed, E. (2008). Theory of mind impairment in right hemisphere damage: A review of the evidence. *International Journal of Speech-Language Pathology*, 10, 414-424.

Weed, E., McGregor W., Nielsen J. F, Roepstorff A., & Frith, U. (2010). Theory of Mind in adults with right hemisphere damage: What’s the story? *Brain and Language*, 113, 65-72.

Winner, E., Brownell, H., Happé, F., Blum, A., & Pincus, D. (1998). Distinguishing lies from jokes: Theory of mind deficits and discourse interpretation in right hemisphere brain-damaged patients. *Brain and Language*, 62, 89-106.

Wolfe, C. (1996). The Burden of Stroke. In C. Wolfe, T. Rudd & R. Beech, (Eds.), *Stroke Services and Research*. (pp. 247- 60). London, UK: The Stroke Association.

Yeh, Z-T. & Tsai, C-F (2014). Impairment on theory of mind and empathy in patients with stroke. *Psychiatry and Clinical Neurosciences*, 68, 612–620.

Table 1

Descriptive statistics for participants with stroke and healthy controls

	RHL Group		LHL Group		HC Group	
	N=15		N=15		N=40	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age (in years)	67.80	14.14	67.73	9.99	66.63	12.74
Education (in years)	11.73	3.08	10.87	2.26	12.13	3.55
NART predicted IQ (score)*	105.40	11.22	101.38	12.08	108.88	9.47
BDI-II score (0-63)	5.20	7.52	4.73	4.17	4.22	4.05
Time post stroke (in days)	71.0	32.49	77.47	32.48	-	-

*Note.** NART score for LHL group is based on the performance of 8 participants, as 7 were unable to complete it due to acquired aphasia. RHL = right-hemisphere lesion, LHL = left-hemisphere lesion, HC = healthy control. NART = National Adult Reading test; BDI-II = the revised Beck Depression inventory

Table 2

Descriptive statistics for Theory of Mind and executive function measures in participants with stroke and healthy controls

	RHL Group		LHL Group		HC Group	
	n = 15		n = 15		n = 40	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<u>Total number of correct responses on</u>						
<i>RMET</i>	10.07	4.11	15.27	2.99	16.42	3.37
<i>Eyes Control task</i>	13.33	3.09	14.47	3.07	15.58	3.47
<i>Category Fluency trial*</i>	12.27	4.68	12.63	5.63	19.52	4.56
<i>Letter Fluency trials (Combined)*</i>	23.13	12.63	26.75	18.98	38.25	12.14
<u>Total number of errors made on</u>						
<i>Brixton test</i>	24.27	8.35	23.93	7.06	16.43	5.19

Note. * The Category Fluency trial and Letter Fluency trials (Combined) scores for LHL group are based on the performance of 8 participants, as 7 were unable to complete them due to acquired aphasia. RHL = right-hemisphere lesion, LHL = left-hemisphere lesion, HC = healthy control. RMET = the Reading the Mind in the Eyes' test.

Table 3

Correlations between the Reading the Mind in the Eyes' Test (RMET) and executive function measures in the three groups

	RMET			Brixton test			Category Fluency		
	RHL	LHL	HC	RHL	LHL	HC	RHL	LHL	HC
<i>Brixton test</i>	-.57 * n = 15	-.18 n = 15	-.15 n = 40						
<i>Category Fluency</i>	.52 * n = 15	.42 n = 8	.34 * n = 40	-.44 n = 15	-.41 n = 8	-.21 n = 40			
<i>Letter Fluency</i>	.28 n = 15	.22 n = 8	.27 n = 40	-.20 n = 15	-.63 n = 8	-.37 * n = 40	.73** n = 15	.69 n = 8	.40 * n = 40

Note. * $p < .05$, ** $p < .01$. RHL = right-hemisphere lesion, LHL = left-hemisphere lesion, HC = healthy control. RMET = the Reading the Mind in the Eyes' test.